

## Scattering from Rock and Rock Outcrops

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### LONG-TERM GOALS

In terms of target detection and classification, scattering from exposed rock on the seafloor, (i.e., individual rocks and rock outcrops) presents some of the most difficult challenges for modern MCM and ASW sonar systems in shallow water. Work on characterizing, modeling and simulating mean levels and other statistical measures of acoustic scattering from rocks and rock outcrops is therefore critical. Unfortunately (and curiously) information on scattering from underwater rock and outcrops is almost non-existent. Scattering from rock outcrops is not simple enough to be encompassed by a single scattering strength curve, but has a variety of expressions depending on the exact geomorphology of the rock. Smoothed surfaces may actually scatter less than surrounding sediment; curvature may dramatically affect scattering and rough areas as seen on the rock outcrop in Fig. 1, display high variability which could pose difficulty for target detection and classification systems.



**Figure 1.** Photo of rock outcrop in the Oslofjord near Larvik, Norway. The outcrop is similar to underwater outcrops from which acoustic scattering was collected.

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The primary long-term goal of this research project is to increase understanding and modeling capabilities for high-frequency acoustic scattering from rock and rock outcrops. In addition to an increase in basic understanding of the characteristics of scattering from rock, any resulting advances in modeling would be useful for improving simulation capabilities and for improving detection and classification tools. Inverse models based on forward models would be essential for using sonar systems for remote sensing of seafloor properties. An understanding of spatial coherence functions for isotropic and anisotropic rough seafloor surfaces could allow a method for separating natural ‘target’-like objects such as rough rock from man-made targets.

## OBJECTIVES

Our objectives for the proposed study of scattering from rocky seafloors and rock outcrops are intended to address many of the open questions which exist for scattering from these types of surfaces and include increasing our basic understanding of:

- 1) geoacoustic characteristics of rock relevant to scattering,
- 2) scattering strength versus grazing angle, and
- 3) coherence in angle or frequency of scattering from rock.

These goals will be achieved through examination of existing literature, analysis of field data or lab measurements and by the use of extended approximate or numerical scattering models.

## APPROACH

The proposed work will involve:

- (1) examining the literature on the morphological and geo-acoustic characteristics of various types of rock (e.g. roughness, facet size distribution, bulk properties),
- (2) acquiring and analyzing acoustic and environmental data collected during field tests in areas of known rock outcrops, and
- (3) modeling acoustic scattering by adapting existing approximate models or using numerical scattering techniques such as finite element or boundary element models.

Using broadband wide-aspect acoustic data (available, for example, from synthetic aperture sonar systems) we will characterize scattering from rock in terms of both mean levels and other statistical measures such as angular or frequency coherence and probability of false alarm (PFA). Data taken on different morphological features of rock outcrops (i.e., surfaces that are smooth, rough, curved, faceted, etc.) will be obtained and analyzed to determine the relative influence of these features on scattering characteristics such as the shape of the scattering strength versus grazing angle curves or the transition to a Lambertian shape. Environmental data consisting of high-resolution sonar measurements (such as from interferometric synthetic aperture sonar systems) taken in the experimental areas will be used as ground truth in data/model comparisons. If environmental data do not exist, we will attempt to collect it as part of this project. Data-model comparisons will yield insight into controlling factors, identify gaps in our knowledge base and highlight deficiencies in our current

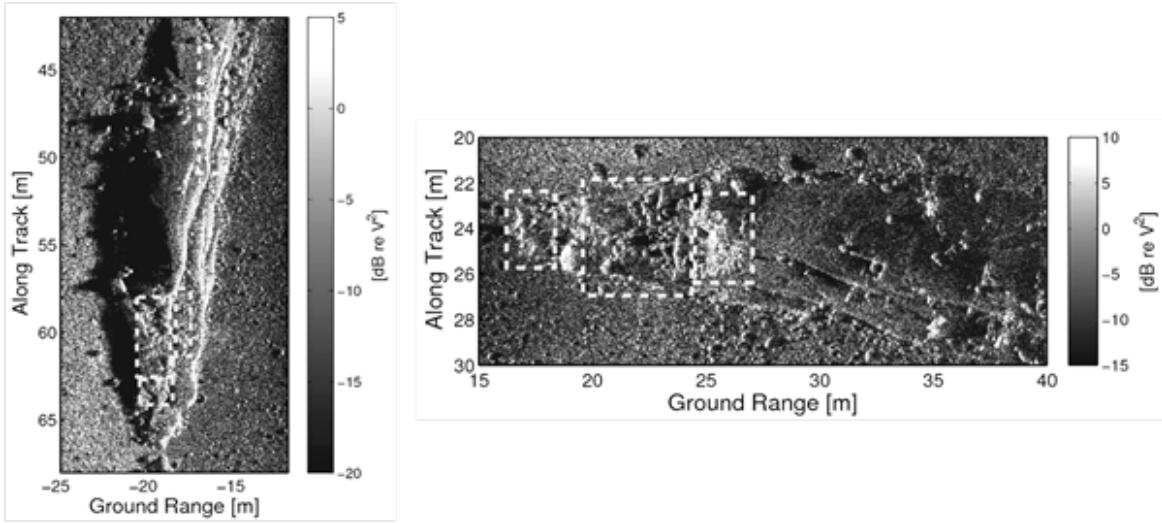
scattering models. Suggestions can also be made for future studies based on knowledge gained in the proposed study.

The groundwork for this study has already been laid via a variety of ongoing projects and collaborations by the PI. Through a joint ARL-PSU research project with the Norwegian Defence Research Establishment (FFI, POC Roy Hansen) and an ONR Code 33 project which ended in FY12, we took part in an at-sea experiment in Oslo Fjord where we acquired 100 kHz SAS data from FFI's HUGIN HISAS system on rocky objects over a wide range of sizes (from less than 1 m up to several 10's of m). The HISAS yields high-resolution interferometric bathymetry (~15 cm resolution) which can be used for estimating curvature and the larger-scale slope field. As part of an ongoing MCM Joint Research Program with the NATO Undersea Research Centre, we have obtained MUSCLE SAS data (300 kHz) on individual rocks and rock outcrops. To aid in the study of angular and temporal coherence we have also obtained SAS data from NURC's 'calibrated' rock with a digitized 3D shape. Additionally, as part of this research project, PhD student, Derek Olson, is exploring scattering from rock outcrops as part of his thesis work. We have also initiated joint research with NRL-DC (R. Gauss) to pass our characterization work on to them for use in lab and numerical scattering studies.

## WORK COMPLETED

Over the course of FY14, work was performed by graduate student Derek Olson and the PI on measuring and modeling scattering from rocky outcrops described in the first two components listed in the technical approach described above. As virtually no information exists on scattering from rock outcrops, we have worked on obtaining relevant physical characteristics of rock outcrops, such as the roughness and morphology for use in models of acoustic scattering from rock. This year the procedure to estimate scattering strength from high-frequency SAS acoustic data was refined.

The sonar data analyzed was collected in April, 2011 during a joint field experiment that took place near Larvik, Norway, as part of a collaborative work with the Norwegian Defence Research Establishment (FFI). The SAS system operated at a center frequency of 100 kHz, has a bandwidth of 30 kHz and was operated from the HUGIN Autonomous Underwater Vehicle (AUV). A sample SAS image of a rock outcrop in the experimental area obtained with FFI's SAS system can be seen in Figure 1. From the Larvik, Norway, trial, estimates of scattering strength below 50 degrees grazing angle were found to range from -15 dB to -55 dB over grazing angles of 0 to 90 degrees and yielded an approximate Lambert parameter of approximately -15 (high). The measured scattering cross section from the leeward (or 'plucked') side exhibited variability on the order of 5 dB and probability of false alarm (PFA) curves were extremely non-Rayleigh with a 'knee' in the curves suggesting two scattering mechanisms were at work as will be discussed later in this report.



**Figure 1. Synthetic aperture sonar images of a large rock outcrop in the Oslofjord near Larvik, Norway, taken from two different look directions. Scattering strength was estimated for the areas outlined in the boxes and are shown in Figure 2.**

Because rough rock surfaces have a very large RMS height compared to the acoustic wavelengths used in sonar systems and do not conform to typical seafloor roughness models, such as the small-slope approximations (SSA), an approximate model that will predict the scattered field is currently not feasible. Scattering behavior for these surfaces is driven by near-specular scattering from step facets, non-local shadowing by neighboring facets, diffuse scattering from convex corners and edges, and multiple scattering from concave corners of the surface. Approximate models cannot capture scattering from these types of surface features and therefore are of little use as predictive models of the statistics of scattering. Given the inadequacy of approximate models we have investigated numerical models, specifically the boundary element method (BEM) to address which of the scattering mechanisms listed above were primarily responsible for the non-Rayleigh scattering statistics.

The models discussed above require roughness parameter inputs for direct comparison to experimental measurements. To address this requirement a second field experiment was carried out in May, 2013, near the 2011 Larvik, Norway, experimental site as part of this project. Both small-scale roughness and other features affecting acoustic scattering from rock, such as facet size were obtained. Analysis continued on this data set in FY2014 and sample results will be presented below.

We are also continuing discussion and coordination with researchers at NRL on their related project, “Modeling of High-Frequency Broadband False Target Phenomena” (project PIs are Roger Gauss, Dave Calvo, and Joe Fialkowski) as well as continuing the joint research project “Characterization and Modeling of Synthetic Aperture Sonar Data,” with FFI (POC - Roy Hansen)

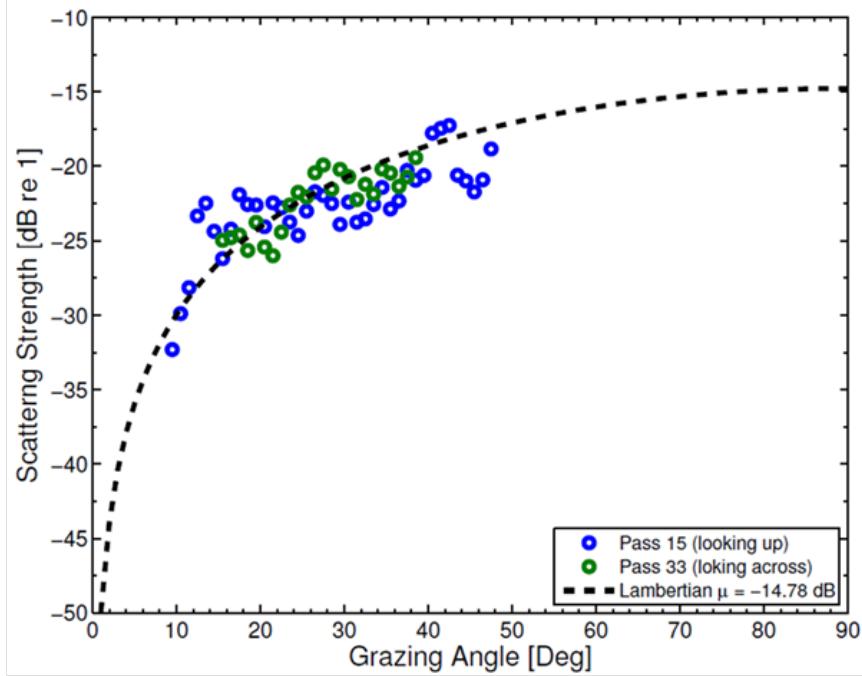
## RESULTS

From the Larvik, Norway, trial, scattering strength from rocks was extracted from the normalized pressure squared by selecting a region and averaging in cross-range, and then averaging over one degree increments. To measure the scattering strength from a rock surface, the mean slope was determined from high-resolution interferometric bathymetry so that the global grazing angle of the

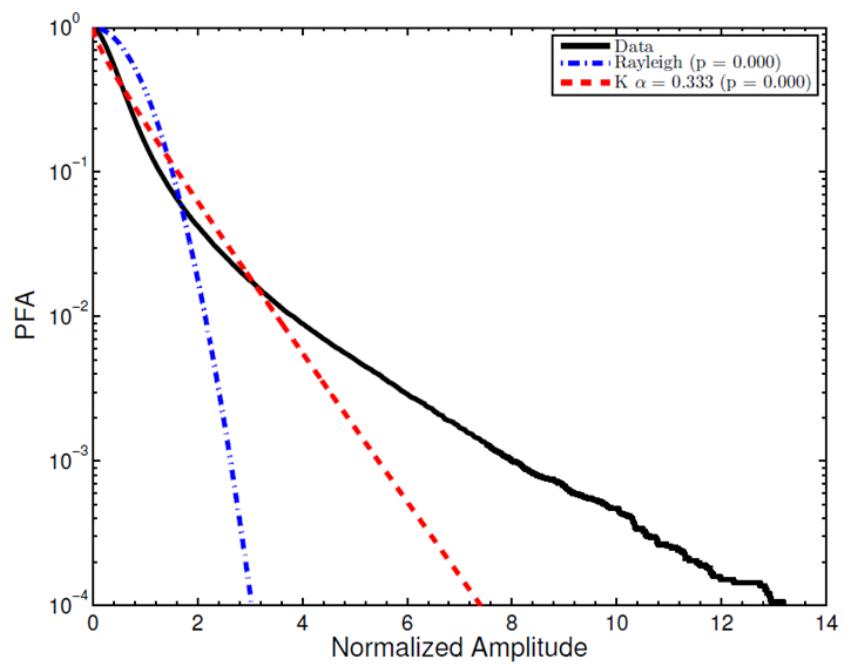
ideal mean seafloor could be mapped to the local grazing angle of the rock. After system calibration, low scattering strengths were found to range from -15 dB to -45 dB over grazing angles of 0 to 90 degrees. The plot in Fig. 2 displays sample scattering strength data taken from a rough portion of a granite rock outcrop and is roughly Lambertian in shape. The rough portions (corresponding to the image in Figure 1) result from glacial quarrying and are composed of steps whose orientations and size distributions reflect the internal fault organization of the bedrock.

The plot in Fig. 3 displays experimentally determined PFA for the same surfaces and is clearly non-Rayleigh. The PFAs exhibit a concave curvature in log-linear space (a ‘knee’), which is not possible with the K-distribution and is suggestive of that the data may require a combination of mechanisms (or mixture model) to fit the curve. The two mechanisms contributing could be scattering from small scale roughness combined with specular scattering from facets oriented close to normal incidence to the sonar system. Diffraction from sharp edges may also contribute strong scattering that is non-directional as for scattering from small scale roughness. The large number of specular points provided by the large roughness causes a large number of high-amplitude events skewing the ‘tail’ of the distribution. A mixture model consisting of Rayleigh and K would be a good candidate to fit PFA from this two-component scattering surface.

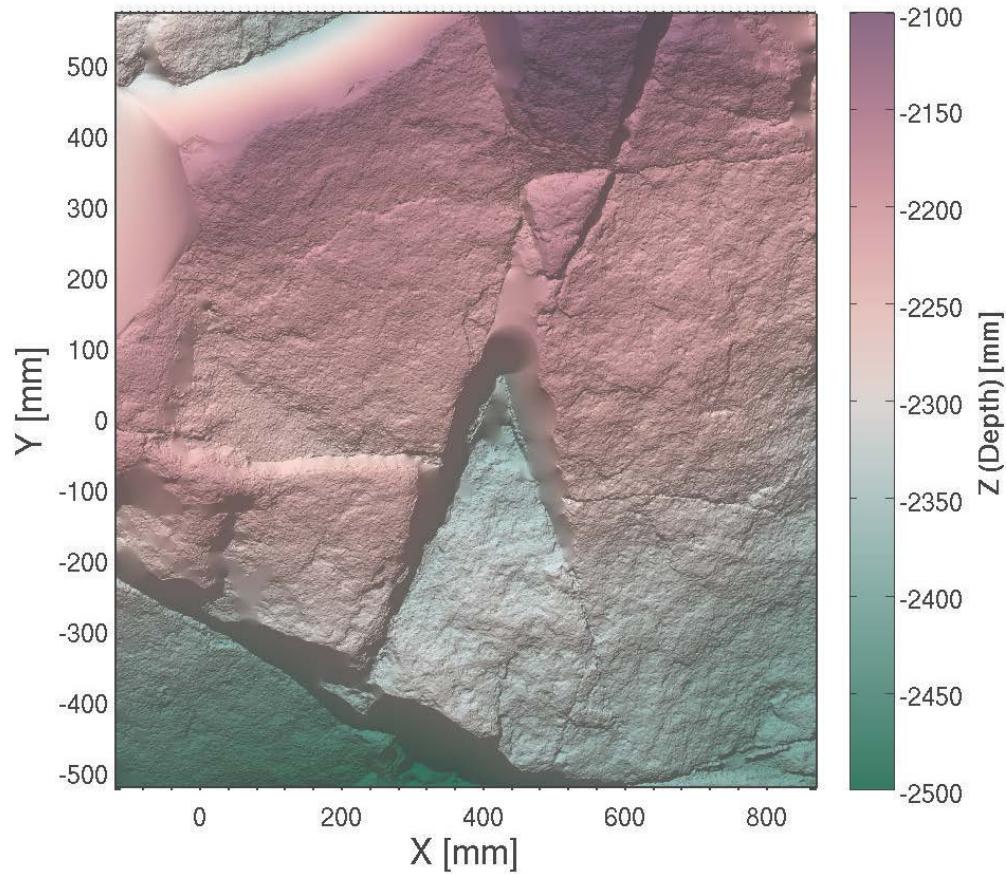
Roughness parameters for use in the surface scattering models developed as part of our research have been collected in a recent field experiment and are currently being analyzed. Figure 6 shows an example of the height field estimated using two images of a stereo pair. Over the next year these height distributions will be used as input to models to make predictions of mean scattered levels and PFA for direct comparison to measured data.



**Figure 2. Scattering strength of rock outcrop at 100 kHz obtained from FFI’s HUGIN HISAS imaging sonar (circles) and a best Lambertian fit.**



**Figure 3.** PFA of rock outcrop at 100 kHz obtained from FFI's HUGIN HISAS system.



**Figure 4.** Estimates of high-resolution roughness taken near Larvik, Norway made with a stereo photogrammetry system.

## **IMPACT/APPLICATIONS**

The primary work completed over the course of this project consisted of developing techniques for modeling scattering from rough rock outcrop areas and comparing results with acoustic data sets collected from rocky areas. The proposed project was designed to increase our understanding of and simulation capability for acoustic scattering from rock outcrops. This study is yielding useful knowledge of rock outcrops as a mechanism responsible for shallow water false alarms and how levels of false alarm relate to physical properties and features of rock outcrops. Guidance relevant to this false alarm mechanism is being provided to researchers at the Naval Research Laboratory and will also be provided to those developing digital simulation content as part of other programs. Other deliverables are journal articles that are in preparation.

## **RELATED PROJECTS**

None